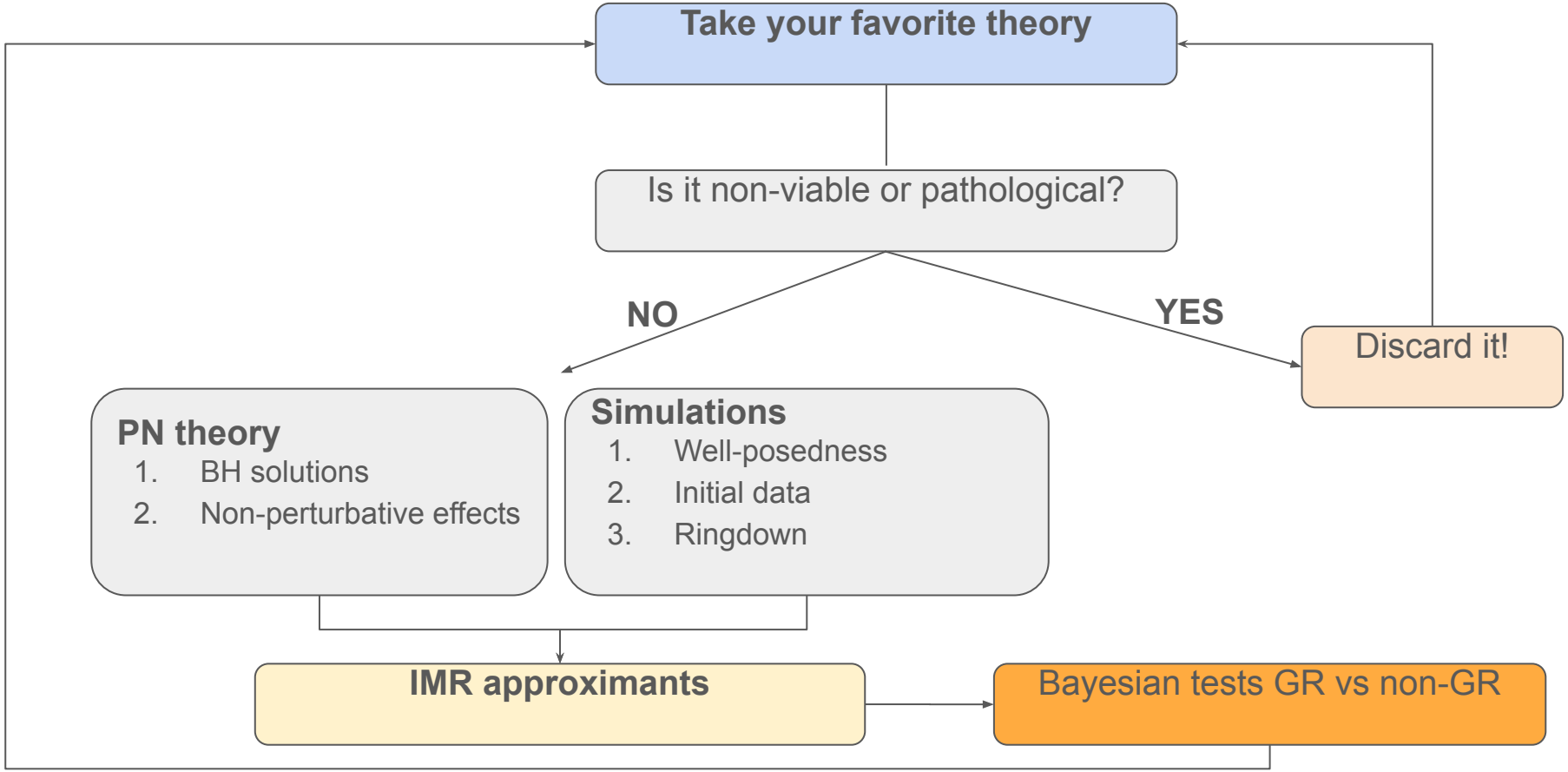
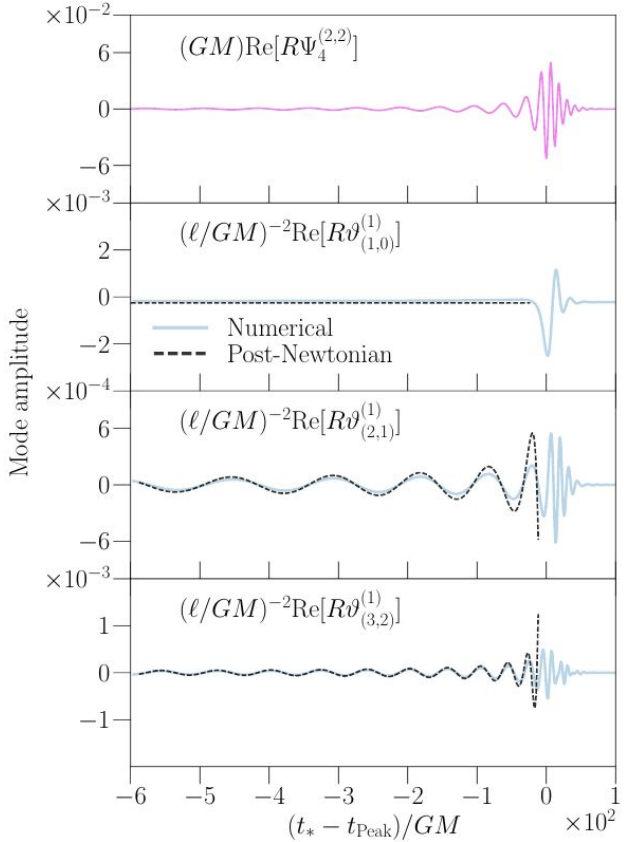
Roadmap for testing a “golden” modified gravity theory



PN and late-inspiral modelling beyond GR

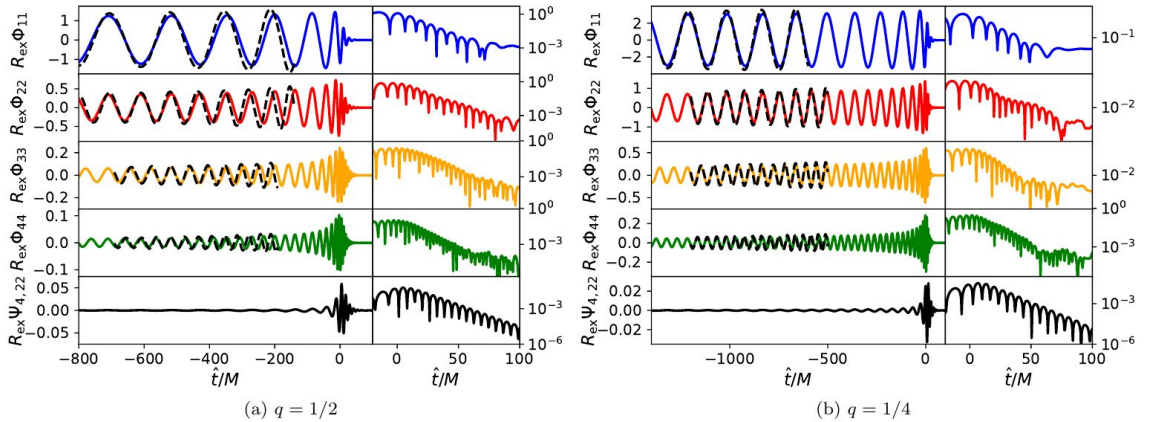
- **Leading-order PN corrections for selected theories:**
  - Scalar-tensor, Quadratic gravity (Gauss-Bonnet, Chern-Simons), Lorentz-violating
  - Mostly leading-order terms → enough?
  - (almost) oblivious to nonlinear effects
- **PN corrections in ECOs:**
  - spin-induced quadrupole moments (2PN*spin^2)
  - Tidal heating (2.5PN*log v * spin)
  - Tidal deformability (5PN * (R/M)^5)
  - Spin-tidal (>=6.5PN)
- **TIGER / ppE formalisms**
  - Model-independent
  - Best for null tests
  - Hard to map back to theories
  - Only perturbative effects
- **EOB**
  - Only in scalar-tensor theories (and partly in EMD gravity) [Felix 2017-2018]
  - Nothing done in other theories or for ECOs

NR beyond GR: nonlinearities,ringdown, scalar modes and all that...



Okounkova+ 2017

Witek+ 2018

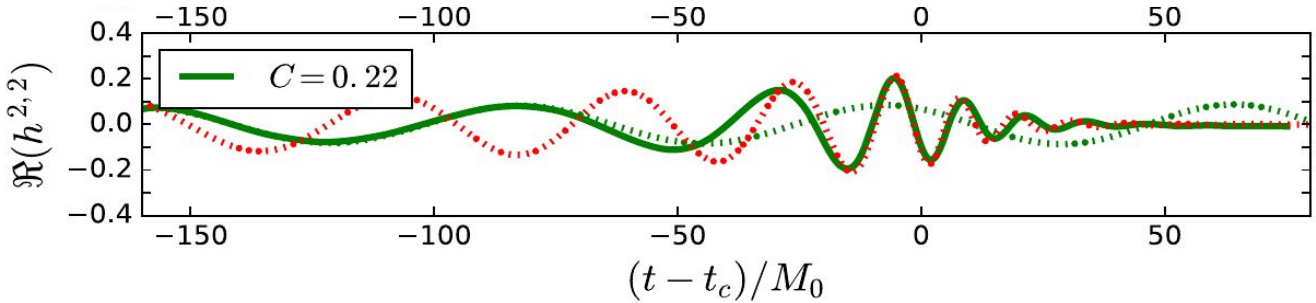


- **Nonlinear effects unpredictable otherwise**
- **QNMs mixing and extra mode**
- **EFT simulations are under control and on-going**

BBSs or BBHs?

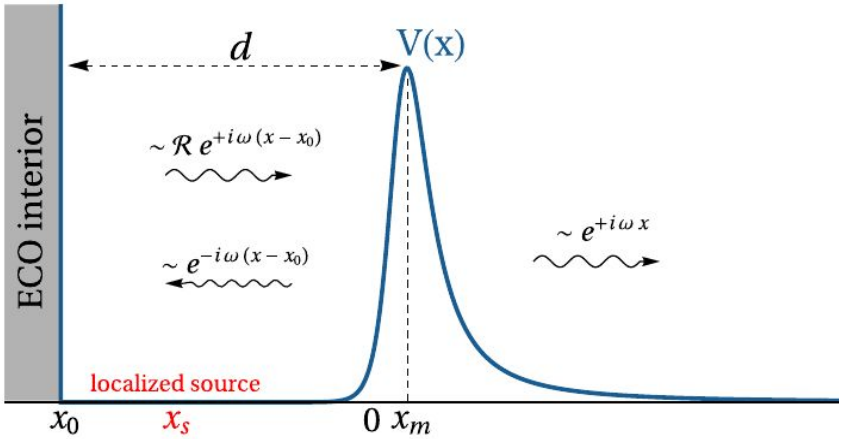
Can BBSs mimic the full signal from BBH coalescence?

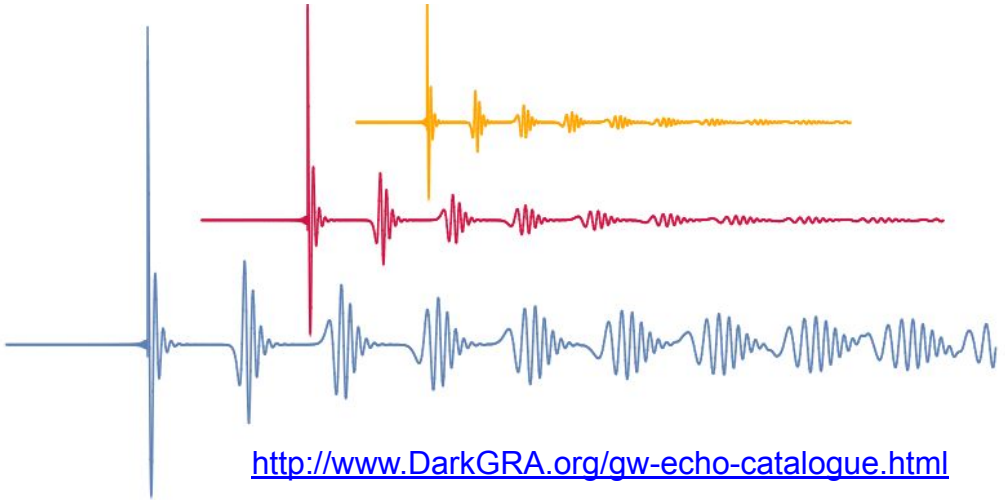
[Palenzula+ 2017]



- "Short-blanket" problem: mimicking IMR signal of BBHs is hard
- Doable and urgent: IMR waveforms for BBSs

GW echoes: modelling



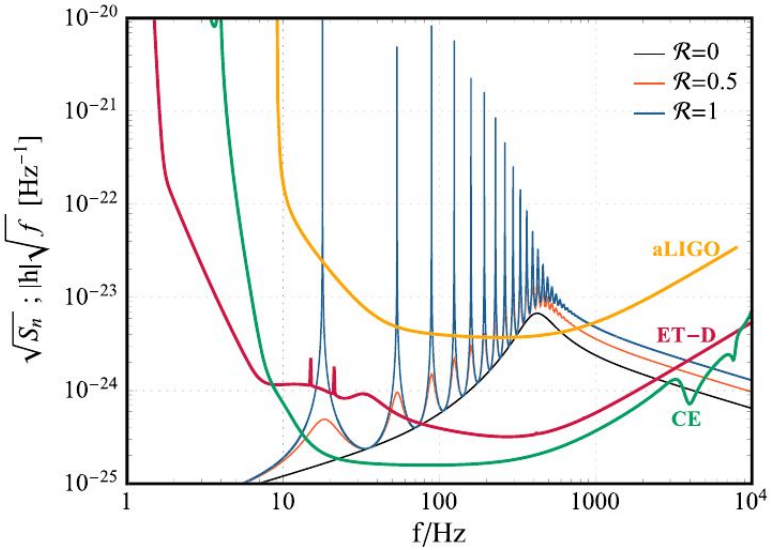


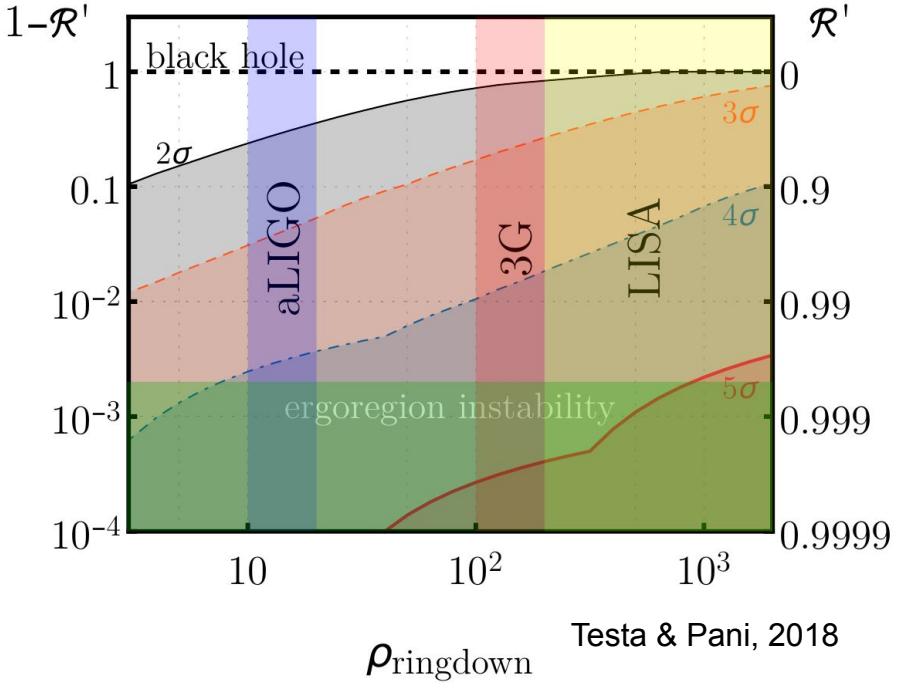
http://www.DarkGRA.org/gw-echo-catalogue.html

- Signal is rich: amplitude/frequency modulation, spin effects, boundaries, …
  - Re-processing through a transfer function [Mark+ 2017]
  - Unmodelled "wavelets" burst searches [Tsang+ 2018]
  - Other approaches [Nakano+ 2017; Bueno+ 2018, Maselli+ 2017, Wang+ 2018, Correia+ 2018, Conklin+ 2018...]
  - Analytical template with physical ECO properties [Testa & PP 2018, Maggio+ (in prep)]

$$\tilde{Z}^{+}(\omega) = \tilde{Z}^{+}_{\rm BH}(\omega) + \mathcal{K}(\omega)\tilde{Z}^{-}_{\rm BH}(\omega)$$

GW echoes: detectability





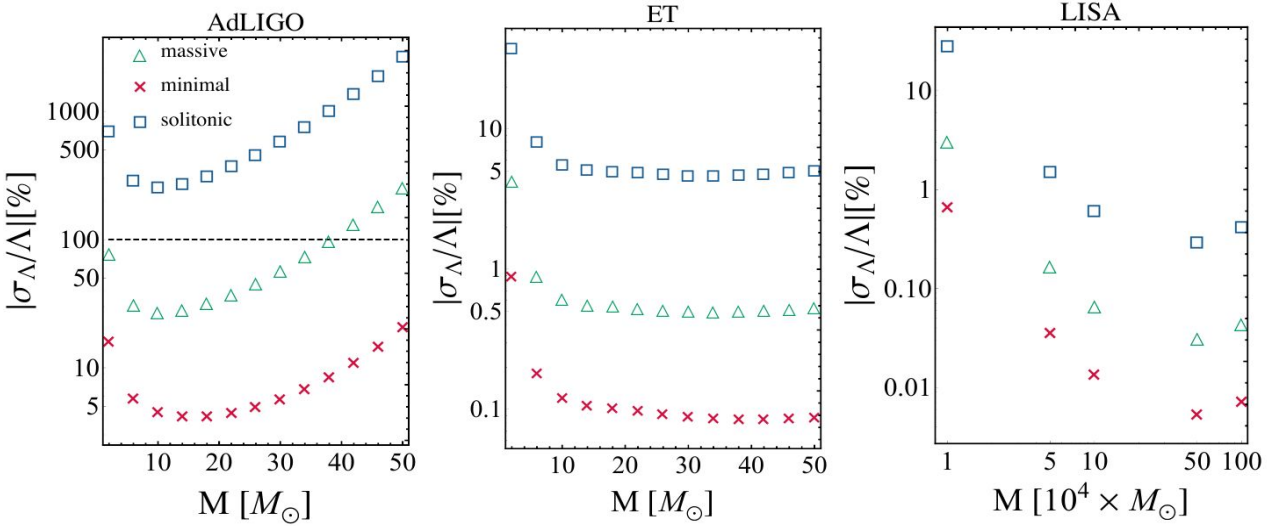
Testa & Pani, 2018

- Echoes might be louder than ringdown, signal strongly depends on reflectivity
- Several developments, but better modeling of echoes waveforms needed

Backup slides

BH/NS vs Boson Stars: Love numbers

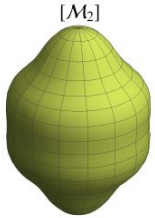
$$\mathcal{L} = \frac{R}{16\pi G} - \partial_\mu \phi \, \partial^\mu \phi^\star - m^2 |\phi|^2 + \lambda |\phi|^4 + \gamma |\phi|^6 + \ldots$$



- aLIGO can exclude only BS vs BH models with relatively small compactness [Cardoso+ (2017), Sennet+ PRD 96 024002 (2017), Johnson-McDaniel+, 1804.08026]
- 3G & LISA will be able to distinguish BHs vs *any* BS model (in different mass ranges)

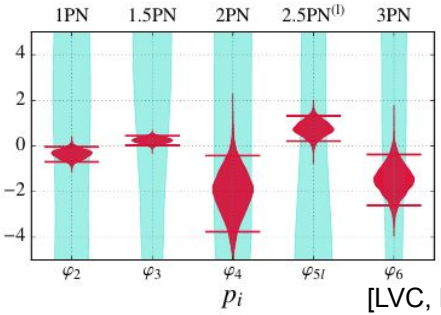
No-hair tests: multipole moments

- **Mass quadrupole moment (M_2) easier to constrain**



$$\bar{M}_2 = -\chi^2 + \delta\bar{M}_2(\chi, \text{coupling})$$

- Comparable-mass inspirals:
  - quadrupole enters at 2PN $\rightarrow \delta\bar{M}_2 \lesssim 0.2$
  - Factor ~20 better with LISA or 3G [Krishnendu+ PRL 2017]
  - Requires highly-spinning BHs (favors LISA?)
  - Complementary to tests of dipolar emission



[LVC, PRL 2017]

- EMRIs:
  - Probe both the multipolar structure and the dynamics (fluxes)
  - More effects: e.g. resonances, floating orbits [Cardoso+, PRL 2011], non-integrable orbits, chaos [Cárdenas-Avendaño+ CQG 2018]
  - Bounds using a phenomenological model [Babak+ PRD 2017] $\rightarrow \delta\bar{M}_2 \lesssim 10^{-4}$
  - Something to discuss: current projected bounds with EMRIs too optmistic? [simplistic waveforms, isolated source in band, enchilada problem]